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SUMMARY

A statewide survey of the parasites of the Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), was made by collecting infested pine tips from 23 locations in South Carolina over a 2-year period. Parasites were allowed to emerge in specially designed cages, were identified, and recorded. A total of 37 species of parasites was recovered, all hymenopterous except one dipterous species. Of these, the ichneumonid, *Campoplex frustranae* Cushman, was the most abundant with the tachinid, *Lixophaga mediocris* Aldrich, following closely in numbers.

Parasitism by locations was shown and comparative parasitism by the two main parasites was listed. It was shown that *Campoplex frustranae* was the most abundant parasite in the Piedmont region and that *Lixophaga mediocris* was the most prevalent in the Coastal Plain region. No definite pattern of dominance could be shown in the Sandhills. The survey recovered 13 species of parasites that were not previously known.

THE PARASITES OF THE NANTUCKET PINE TIP MOTH IN SOUTH CAROLINA

R. D. EIKENBARY[1] and RICHARD C. FOX[2]

INTRODUCTION

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), is a very injurious insect that infests all of the southern pines except eastern white pine and longleaf pine. It is difficult to control using conventional methods and such controls involve heavy expense under reforestation conditions. Crop trees require many years to mature, and the value of the annual growth per acre is low when compared to other agricultural crops. Thus, protective measures must be correspondingly low in cost or relied upon only in an emergency pending the reestablishment of natural controls. However, a tree plantation is an unnatural forest condition, and injurious tree pests frequently build up quickly and cause serious damage. These and other factors have stimulated interest in biological control using species of insects that are parasitic upon the Nantucket pine tip moth.

Investigational surveys of the parasites of the pine tip moth have been made in several areas within the insect's geographic range. The relative densities of the major parasites with respect to one another are not the same throughout the entire range of the host insect. For example, *Macrocentrus ancylivorus* Rohwer is the most prevalent parasite in Arkansas but has been recovered only once in 3 years of study as a parasite of the tip moth in South Carolina. Preliminary surveys in South Carolina have shown *Campoplex frustranae* Cushman to be the most prevalent parasite in many areas; but only two specimens of this insect have been recovered in surveys in Alabama (Hyche, 1963) and it has never been collected in Arkansas (Warren, 1963).

The principal objective of this research was to make a comprehensive survey of the parasites of the Nantucket pine tip moth in South Carolina to test the theory that the wide differences in terrain and climate of this state may be in some way responsible for parasite species differences.

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REVIEW OF PREVIOUS INVESTIGATIONS IN SOUTH CAROLINA

Prior to the present statewide investigation, Anderson (1962), Childress and Fox (1962), and Eikenbary (1963) made studies of the parasite complex of the Nantucket pine tip moth. In each of the investigations, *Campoplex frustranae* (Comst.) was found to be the dominant parasite in the Piedmont region of South Carolina. Fourteen other species of hymenopterous parasites in 10 families and one dipterous species were recorded by these research workers as being parasitic on *R. frustrana.* The species of parasites recovered by these investigations are shown in table 1. It should be noted that *Orgilus* sp. (Hymenoptera, Braconidae), *Sympiesis* sp. (Hymenoptera, Eulophidae), and *Tridymus* sp. (Hymenoptera, Pteromalidae) were not recovered again although extensive sampling was made in these same sample areas.

TABLE 1.—NANTUCKET PINE TIP MOTH RECOVERIES PRIOR TO 1963.

Species of parasites	Parasites recovered by		
	Anderson	Childress and Fox	Eikenbary
Agathis sp.	X		
Campoplex frustranae Cush.	X	X	X
Eurytoma pini Bugbee	X	X	X
Bracon gelechiae (Ashm.)		X	X
Bracon gemmaecola (Cush.)		X	X
Bracon mellitor Say	X		
Perilampus fulvicornis Ashm.		X	X
Eupelmus sp.		X	X
Lixophaga sp.		X	X
Spilochalcis flavopicta (Cress.)	X	X	X
Haltichella rhyacioniae Gahan	X	X	X
Habrocytus thyridopterigis Howard		X	X
Eupelmus cyaniceps Ashm.		X	X
Hyssopus thymus Girault			X
Orgilus sp.		X	X
Sympiesis sp.			X
Tetrastichus sp.			X
Tridymus sp.		X	X
Apanteles sp.		X	

Methods and Materials

To observe the degree of parasitism, the species of parasites, and the relative importance of each in South Carolina, pine tips infested with *R. frustrana* were collected at 17 locations in 1963 with six other areas added in 1964. In selecting sample areas, more attention was paid to geographic location than to tree species present although, in each general area, an attempt was made to find natural or planted stands of loblolly or shortleaf pine. This arbitrary decision was made because it was well known that the host insect, the pine tip moth, was distributed universally, and the primary objective

IN SOUTH CAROLINA

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OVERIES PRIOR TO 1963.

Parasites recovered by	
Childress and Fox	Eikenbary
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
X	X
	X
X	X
	X
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X	

erials

e species of parasites, and Carolina, pine tips infested ocations in 1963 with six mple areas, more attention o tree species present al- was made to find natural pine. This arbitrary deci- n that the host insect, the and the primary objective was to obtain sampling from the three geographical areas of the state—the Piedmont, the Sandhills, and the Coastal Plain. Sample area locations are shown in figure 1.

Figure 1.—Sample area locations—Nantucket pine tip moth parasite survey.

At each sample area, a minimum of 30 infested pine tips was collected at random from the upper crowns of infested trees. After stripping the needles from the apical portions of the tips (for easier observation), ten tips were placed in each of three cages specially designed for this study (see figure 2), and each cage was marked with the appropriate collection date and locality. Each cage had wet, sterile sand in its base to serve as an anchoring medium as well as to keep the tips from drying out before host and parasite development was completed. The cages were brought into the laboratory where temperatures ranged from 77 to 84° F. and the relative humidity ranged from 62 to 67 percent. Emerging tip moth and parasite adults were recovered daily, were identified and tallied, or were preserved for identification by specialists at the U. S. National Museum.

Figure 2.—Parasite-rearing cages, dismantled on left and intact on right.

In 1963, collections started in mid-April and, to provide an adequate overlapping of generations, continued every 3 weeks until late November when the host forms had entered the overwintering (pupal) stage and parasite emergence had ceased. Collections resumed in February 1964 and were terminated in late November.

During the course of these studies, observations of the biological activities of the parasites were made to strengthen the available data on their activities. Development of external parasites was followed by placing single host larvae or pupae in gelatin capsules and observing them through a binocular microscope. The activities and habits of internal parasites were studied by dissecting *R. frustrana* larvae or pupae.

A related experiment was established to test the effects of height, direction, and the number of host forms per tip upon the percentage of parasitism. Fox and King (1963) have shown that, for survey purposes, a tree can be considered to consist of two levels. Thus, two heights were evaluated, with the upper level consisting of the terminal whorl of branches of each tree and the lower level as that part below the terminal whorl of branches.

Infested pine tips were collected from four quadrants—north, east, south, and west—using a quadrant locator constructed from

on left and intact on right.

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aluminum conduit. This device was aligned over the tree with a staff compass. Eight samples were taken from each quadrant, four from the upper level and four from the lower level. Each sample consisted of 10 immature *R. frustrana,* which gave a total of 320 tip moth immatures per tree. Three locations, one each near Clemson, Pendleton, and Seneca, thus resulted in 960 individuals. The larvae or pupae were placed individually in size 3 gelatin capsules and were stored at a temperature of 78° F. ± 4° F. at a relative humidity of 62 ± 5 percent. These were transferred later to petri dishes containing moist filter paper. The emergence of parasites and adult tip moths was checked and recorded daily. Additional collections were made in these areas to study the effect of parasitism in pine tips which contained one, two, three, and four or more tip moth immatures per tip. The significance of parasitism based on all of these experiments was tested by applying the analysis of variance.

Results

Table 2 shows the various parasites and the numbers of each species that were collected during the surveys of 1963 and 1964. A total of 37 different species of parasites was collected with these all in the order Hymenoptera except the one dipterous species, *Lixophaga mediocris* Aldrich. There were 12 families recovered with the Ichneumonidae being most abundant in numbers, but the Braconidae were represented by the greatest number of species. The ichneumonid, *Campoplex frustranae* Cushman, was the most abundant species during both years of the survey with the tachinid, *Lixophaga mediocris* Aldrich, following closely in numbers. Other species that were collected regularly were the eurytomid, *Eurytoma pini* Bugbee, and at least three species of the genus *Hyssopus* (Eulophidae). This latter group was found mainly in the Coastal Plain in South Carolina and coincides with records from Alabama where the genus *Hyssopus* contains important parasites of the tip moth. Another significant result was that in the two seasons of statewide survey only one specimen of *Macrocentrus ancylivorus* Rohwer was collected. As mentioned before, this is the most important parasite of the pine tip moth in Arkansas and is known to be present in South Carolina as a parasite of the oriental fruit moth. This recovery was made at the Brownsville location in 1963. This sample area had a peach orchard nearby. The three main species of parasites, *Campoplex frustranae, Lixophaga mediocris,* and *Eurytoma pini* made up 62 percent of the total parasites collected in 1963 and 56 percent in 1964.

TABLE 2.—PARASITES OF *Rhyacionia frustrana* (COMSTOCK) FOUND IN SOUTH CAROLINA IN 1963 AND 1964.

Family and species	Number collected—1963	Number collected—1964
DIPTERA		
Tachinidae		
Lixophaga mediocris Aldrich	164	332
HYMENOPTERA		
Bethylidae		
Goniozus electus Fouts	8	17
Braconidae		
°*Agathis acrobasidis* (Cush.)	26	40
°*Apanteles petrovae* Walley	34	46
Apanteles sp.	—	4
Bracon gelechiae (Ashm.)	8	16
Bracon gemmaecola (Cush.)	27	36
Bracon sp.	2	5
Macrocentrus instabilis Mues.	5	7
Macrocentrus ancylivorus Roh.	1	—
°*Pauesia gillettei* (Gahan)	2	12
Pauesia sp.	—	9
Chalcididae		
Spilochalcis flavopicta (Cress.)	9	15
°*Spilochalcis leptis* Burks	1	3
Haltichella rhyacioniae Gahan	16	33
°*Brachymeria molesta* Burks	1	2
Elasmidae		
Elasmus setosiscutellatus (Cwfd.)	1	2
Eulophidae		
Hyssopus thymus Girault	17	29
°*Euderus argyresthiae* (Cwfd.)	1	3
°*Tetrastichus coerulescens* Ashm.	1	2
Hyssopus rhyacioniae Gahan	2	19
Hyssopus sp.	4	103
Eupelmidae		
Eupelmus cyaniceps Ashmead	7	16
Eupelmus sp.	14	32
Eurytomidae		
°*Eurytoma pini* Bugbee	80	178
Ichneumonidae		
Campoplex frustranae Cush.	271	483
Cremastus sp.	—	1
°*Exeristes comstockii* (Cress.)	12	21
Itoplectis conquisitor (Say)	12	22
°*Pristomerus* sp.	16	29
°*Temelucha epagages* (Cush.)	1	3
Temelucha sp.	6	18
Perilampidae		
Perilampus fulvicornis Ashm.	30	47
Platygasteridae		
°*Platygaster* sp.	1	—
Pteromalidae		
Habrocytus sp.	1	18
°*Habrocytus phycidis* Ashm.	—	14
Pteromalini, Unknown genus and species	—	6
Total	785	1,648

° New record according to Yates (1960).

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	Number collected—1963	Number collected—1964
...	164	332
A		
...	8	17
...	26	40
...	34	46
...	—	4
...	8	16
...	27	36
...	2	5
...	5	7
...	1	—
...	2	12
...	—	9
...	9	15
...	1	3
...	16	33
...	1	2
...	1	2
...	17	29
...	1	3
...	1	2
...	2	19
...	4	103
...	7	16
...	14	32
...	80	178
...	271	483
...	—	1
...	12	21
...	12	22
...	16	29
...	1	3
...	6	18
...	30	47
...	1	—
...	1	18
...	—	14
...	—	6
...	785	1,648

Table 3 shows the comparative parasitism by locations for the 2 years. The great variation which is evident was expected and the only consistent result is that parasitism at Hodges and Jonesville was the lowest during both years. The other locations varied from one extreme to the other or remained at about a given level of parasitism.

TABLE 3.—APPARENT PARASITISM* *Rhyacionia frustrana* (COMSTOCK) AT VARIOUS LOCATIONS IN SOUTH CAROLINA IN 1963 AND 1964.

Location	1963			1964		
	No. of hosts	No. of parasites	Percent of parasitism	No. of hosts	No. of parasites	Percent of parasitism
Andrews	78	32	29.1	61	83	57.6
Brownsville	83	77	48.1	181	83	31.4
Camden	**			413	146	26.1
Chester	73	32	30.5	204	58	22.1
Chesterfield	91	37	38.9	196	94	32.4
Clemson (S)	63	29	38.4	151	66	30.4
Clemson (N)	125	81	39.3	214	66	23.6
Columbia	**			78	39	33.3
Edgefield	112	68	37.8	220	88	28.6
Gresham	65	34	34.3	158	83	34.4
Hodges	168	65	27.9	318	47	12.9
Jonesville	69	29	29.6	292	44	13.1
Laurens	**			216	47	17.9
Orangeburg	**			166	207	55.5
Pacolet	53	28	34.6	136	83	37.9
Pendleton	177	87	31.6	202	28	12.2
Salem C. R.	**			140	74	34.6
Seneca	191	85	30.8	223	66	22.8
Smoaks	91	54	37.2	102	105	50.7
Summerton	**			229	121	34.6
Summerville	32	30	48.8	124	66	34.7
Tradesville	43	50	53.6	252	61	19.5
White Pond	31	24	43.6	72	25	25.8

* Percent parasitism is based upon the assumption that only one parasite emerges per host.
** Collections of host material were made only in 1964.

Parasitism in the three geographical areas of the state (Piedmont, Sandhills, and Coastal Plain) was slightly different for the two major parasites, as shown in table 4. Although not shown in the table, parasitism by location ranged from a low of 22.7 percent to a high of 52.1 percent in 1963 and from 5.0 percent to 58.3 percent in 1964. *Campoplex* appeared to be more important in the Piedmont and *Lixophaga* in the Coastal Plain. Total parasitism for both species was similar in both years accounting for 53.8 percent in 1963 and 53.4 percent in 1964. Also, in 1963 the higher parasitism oc-

curred in the Coastal Plain, and in 1964 this changed to the Sandhills locations.

A detailed discussion of the effect of direction, number of hosts per tip, and the level of tree on parasitism is in preparation, but it can be said at present that the south-lower level was the least infested by the tip moth while the south-upper level had the greatest infestation. Regarding parasitism, it was found that there was a significant difference of parasitism among locations and between the height levels, but there was no significant difference for the four directions studied or for the number of tip moths per tip or the interactions produced by these factors.

TABLE 4.—PARASITISM OF *Rhyacionia frustrana* BY *Campoplex frustranae* AND *Lixophaga mediocris* IN SOUTH CAROLINA IN 1963 AND 1964.

	1963			1964		
Area	Total[1] % Paras.	% of[2] Par. *C. f.*	% of[3] Par. *L. m.*	Total[1] % Paras.	% of[2] Par. *C. f.*	% of[3] Par. *L. m.*
Piedmont	31.4	47.3	14.1	21.3	36.0	13.0
Sandhills	18.7	41.2	29.4	41.4	13.8	17.2
Coastal Plain	45.2	17.5	23.8	38.3	29.2	37.5

1 Total percent parasitism.
2 Percent of parasites *Campoplex frustranae*.
3 Percent of parasites *Lixophaga mediocris*.

Conclusions

This study has pointed out that parasites are important in reducing tip moth populations, but nowhere in the state have parasites alone been effective in preventing infestation. The survey showed four insects that were responsible for most of the parasitism—*Campoplex frustranae, Lixophaga mediocris, Hyssopus* sp., and *Eurytoma pini. Campoplex* has been the most important one in the Piedmont and *Lixophaga* has assumed this position in the Coastal Plain, but no definite pattern of dominance could be shown in the Sandhills.

This survey has been adequate to point out the various parasites that regularly are present from year to year, but future studies will be needed to determine some of the interactions that are found in association with the tip moth.

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	1964		
% of[3] Par. *L. m.*	Total[1] % Paras.	% of[2] Par. *C. f.*	% of[3] Par. *L. m.*
14.1	21.3	36.0	13.0
29.4	41.4	13.8	17.2
23.8	38.3	29.2	37.5

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